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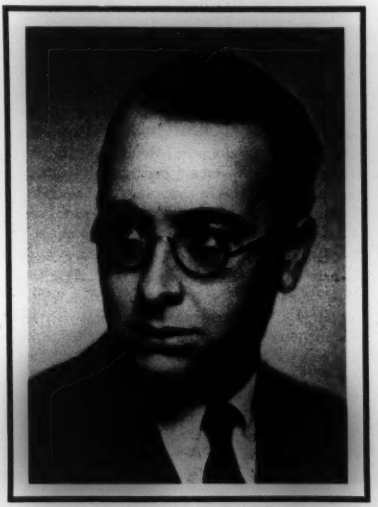
Stanley Whitehead



By the sudden death of Dr. S. Whitehead, its Honorary Treasurer, at the early age of 53, the Institute has lost one of its staunchest supporters. He gave his life to physics, electrical engineering and education of the young. It was typical of the man that during the last few months of his life, when he was in failing health, he suffered acute mental distress because he believed that his services were not always up to the exceptionally high standards he set himself. Although pressed, he steadfastly refused, until a few weeks before the end, to allow himself rest from the worries and anxieties that come the way of all leaders.

Dr. Whitehead was educated in London at the Sir Walter St. John's Grammar School and graduated in physics at Oxford where he carried out research with Professor Lindemann (now Lord Cherwell). From there he went to the Electrical Research Association in 1925 and remained in its service until his death, becoming Director in 1946. It is a tragedy that he did not live to see the move to the new laboratories at Leatherhead which is about to take place.

His own research work was chiefly concerned with dielectrics and their physical properties. He was the author of four books and of many original papers on this and allied subjects. Whitehead was a brilliant research physicist and a mathematician of no mean order, and he was able to apply his learning to electrical engineering, a rare and valuable combination.

His connection with the Institute goes back nearly thirty years, when he was elected to Associateship ; he gained his Fellowship in 1934. Ten years later he was elected Chairman of the London and Home Counties Branch of the Institute and became an ex-officio member of the Board. He was elected a Vice-President in 1949, an office he held until his election as Honorary Treasurer in 1951. He was Chairman of the Finance and General Purposes Committee and of the Benevolent Fund Committee and took an active part in the work of many other Institute Committees. He represented the Institute on many outside bodies.

He was active too in the Institution of Electrical Engineers ; he had been Chairman of its Measurements Section, and was Chairman of the Management Committee of Science Abstracts. He was a Manager of the Royal Institution ; and he had been one of the Honorary Secretaries of the Parliamentary and Scientific Committee. He was Chairman of the Governors of his old school and had recently been Chairman of the Committee of Directors of Research Associations. He served on many national and international committees, and was Chairman of several of them.

Apart from his scholarship and high principles in the practice of his profession, perhaps his outstanding characteristic was his love of service to his fellow men. This was seen again and again, in his handling of Benevolent Fund cases, in the help he gave European scientists who had suffered political oppression in the 1930s, and indeed to all who came to him with their difficulties.

The Institute and many individuals have lost a guide, philosopher and friend whose memory they will always cherish. Members' sympathy will go out to his widow, son and daughter in their irreparable loss.

H. R. LANG.

At Dr. Whitehead's funeral, which took place at St. Mary's, Hampton, Middlesex, in the presence of a large congregation, the Institute was represented by Mr. O. W. Humphreys (*Senior Vice-President*) and the Secretary ; several other Fellows were also present. The very many floral tributes included one from the President and Board and another from the staff of the Institute.

Vol. 7, June, 1956

Science and Technology in Industry*

By SIR JOHN COCKCROFT

K.C.B., C.B.E., D.Sc., M.I.E.E., F.Inst.P., F.R.S.

(Director, Atomic Energy Research Establishment, Harwell)

THE EARLY INDUSTRIES in this and other countries were based on craft skills, arts and inventions rather than science. Examples of this are the textile, metallurgical, ceramic and early engineering industries. The electrical industry and chemical industry founded in the last century were on the other hand based firmly on the discoveries of science. In the present century applied science and technology are playing a rapidly increasing part in the development of industry. It is important now to be aware of these trends so that we can make provision during the next decade to train the scientists and technologists who will be needed if we are to maintain our place in the world.

APPLICATIONS OF SCIENCE AND TECHNOLOGY

I will first remind you of some outstanding examples of the way science and technology has recently founded new industries. Radar and allied technology developed during the war years is my first example. I remember very well seeing the first 10 cm. wave length magnetron developing a pulsed power of 10 kW connected up to a vacuum pump in a hut on the downs of St. Albans Head in Dorset in the middle of 1940. This was a technical revolution increasing a thousand fold the power available for short wave radar. This magnetron had been devised by academic physicists working in Professor Oliphant's laboratory in the University of Birmingham. Within a few months it had been applied to centimetre radar sets installed in destroyers and corvettes for the war at sea. I remember seeing in 1941 the first 3 cm. radar set looking out for a submarine in Swanage Bay under the direction of Professor Skinner. During the next four years at least two thousand scientists and technologists in Government establishments and industry worked to apply this centimetre radar development to a whole range of objectives. To-day every ship of any size has its 3 cm. radar set; every airport has rotating scanners controlling traffic and other radar sets to talk down planes through haze and fog. Without it the modern density of air traffic would be impossible. The annual output of the U.K. electronic industry in radar and allied devices is now about £60 million per annum of which about 20% is exported.

The development of computors is another interesting example. The digital computor may be said to have been born when Dr. Wynn-Williams in the Cavendish Laboratory about 1929 developed the scale-of-two counter. I remember how indebted we were in our then state of penury to the British Thomson-Houston Co. Ltd. for presenting two thyratrons for this work. From this small beginning scale-of-two counters multiplied and spread into most laboratories of the world, whilst after the war high speed digital computors based on scale-of-two operation were developed. An important example was the work of Professor F. C. Williams in the University of Manchester which led to the Ferranti high speed digital computor. This computor can work at least a million times faster than a mathematician equipped with a slide rule or tables of logarithms and can solve problems which no mathematician can solve in finite time. The development of this com-

* A public lecture given by the President of the Institute at a one-day Conference on "Physics in Industry" arranged by the South Wales Branch in Cardiff on Friday, April 13, 1956.

putor was made possible by the catalytic investment of the National Research and Development Corporation. Up to the present, nine of these computors have been made ; their use, which started in Government research establishments, will soon be spreading through industry and the universities. Other U.K. examples are the Ace and Deuce Computors resulting from the work of the National Physical Laboratory's Mathematical Division and of The General Electric Co. Ltd. The expenditure on research and development on computors in Britain since the war has been about £1·4 million.

If we look at the other side of the Atlantic the expenditure on digital computors and automatic control has been about 250 million dollars. The number of types of U.S. computor is now legion. A single computor—the International Business Machines Corporation's Type 704—commands an annual rent of £250,000.

The International Business Machine Corporation has orders for about 200 of its big computor models of which thirty are installed. Over 1,000 million dollars of capital is being invested in electronic computors or data processors and the U.S. computor output seems to be more than 100 times the U.K. output. There are already 100,000 computor engineers and technicians employed in the U.S. and these numbers are rapidly increasing.

Why is it that the use of high speed computors is spreading so rapidly ? The answer is that there are many fields of work which are only made possible by their use. One example is the hydrogen bomb. The testimony in the Oppenheimer case showed that its development was only made possible by the use of high speed computing facilities—so complex are the processes occurring. In our work on reactors for civil purposes we find also that the difficult calculations can only be done with any reasonable accuracy by the use of computors like the Ferranti or Ace. The large atomic particle accelerators now being constructed to accelerate protons to energies of 25,000 MeV requires the orbits of these particles to be contained within an 8 × 16 cm. vacuum tube during 500,000 revolutions during which time they travel several hundred thousand miles. Perturbations due to very small irregularities in the guiding magnetic fields can easily induce oscillations which throw the particles out of the orbits. All this must be computed, requiring months of work even by the high speed machines. As a result of this we can proceed to build the 25 billion volt European machine at Geneva costing £7 million with a reasonable degree of faith that it will work.

Other applications of the computor are to accounting and management where they are expected in the United States to revolutionize managerial methods. Essentially they enable the detailed operation of an organization to be analysed and fed extremely rapidly to the management. Thus the Monsanto Company is receiving detailed cost figures on each of its products every month instead of once a year. Aviation companies are getting results of prototype flight tests within days instead of weeks which means that the information keeps pace with the tests instead of lagging behind them. Tests on guided missiles produce a vast amount of data through telemetering ; only a computor enables this to be analysed rapidly enough to be useful. The Industrial Group of the U.K.A.E.A. is now using an I.B.M. to keep continuous records and control of its stocks and to control costs of operation. One is in use at Harwell for the analysis of scientific data.

Another impressive example of electronic development is the transistor valve. This is a remarkable example of the application of fundamental solid state physics carried out by Dr. Shockley and his colleagues at the Bell Telephone Laboratories in New York. The semi-conductors germanium and silicon are produced in single crystal form in extremely high degrees of purity—impurity contents have to be less than one part per million. To this pure germanium or silicon is added very small amounts of controlled impurities such as arsenic in specific regions of the crystal. These impurities are diffused into the crystal and form layers which are extremely sharply defined geometrically. With suitable geometry and electrodes the

crystal valve can be either a diode or a triode and rectifiers, amplifiers, oscillators become possible. The amplifier or oscillator is characterized by a very low voltage and low overall power input. Already the oscillators and amplifiers can deal with frequencies up to 100 Mc/s so they can cover most of the range of radio communications. The manufacture of transistors now exceeds a million a year and before long they are likely to outnumber thermionic tubes.

The very low power and voltage requirements of the transistor will enable new kinds of electronic equipment to be developed—thus it seems likely that in the telephone industry switching operations which at present are a combination of relay and thermionic devices will soon be entirely "transistorized" thus greatly reducing maintenance. Match box hearing aids and cigarette case radio receivers have already been produced in large numbers, and the transistor hearing aid sales reached a value of about a million dollars per annum in U.S. a year or two ago. All this has developed from the fundamental work of Dr. Shockley and his colleagues backed up later by the enormous applied research and development effort of the Bell Laboratory.

Another electronic example is the development of instruments for use in atomic energy and the application of radioactive isotopes produced in atomic piles. A simple example of this is the thickness gauge. A radioactive source such as strontium 90 emits high speed electrons which travel through sheet metal as it comes out of a rolling mill. An instrument on the other side measures the intensity and since this diminishes with increasing thickness the sheet thickness can be continuously monitored and the thickness controlled. It is also possible to measure and control the thickness of a coating such as tin on tin plate by measuring the electrons scattering back from the tin layer. In this way the thickness of tin can be controlled to a few hundred thousandth parts of an inch.

Another example is an electronic analytical tool known as the "square wave polarograph" invented by Dr. Barker at Harwell. This instrument can measure continuously impurity contents of liquids down to one part in a hundred million. It now has important control functions in chemical operations.

Instruments of this and many other types have been developed by electronic staff of the Harwell establishment during the last ten years in close collaboration with industry. A walk through the stands of the Scientific Instrument Manufacturers Association of Great Britain Ltd. at the Geneva Conference showed a very impressive display of instruments resulting from this collaboration. About 450 different types of instruments have resulted and the annual output is now worth about £10 million. This has resulted from development work—costing perhaps £250,000 a year—a multiplication factor of 40.

The development of nuclear power is a still more impressive example. In this country now we probably have about 1,000 scientists and technologists working on nuclear power development. In the United States the number of scientists and technologists is ten times greater.

The first result of the British effort will be the Calder Hall power station to be opened by H.M. the Queen next October. In this power station the usual coal fired furnace is replaced by two nuclear reactors. These reactors consist of a huge pressure drum, thirty-seven feet in diameter, containing a core of bricks of very pure graphite. In vertical channels in the graphite bricks hang rods of uranium metal about one inch in diameter sheathed in a light alloy. In other vertical channels control rods hang. These move into and out of the core to control the chain reaction in the uranium. When the chain reaction is proceeding heat is developed in the uranium metal rods. This is transferred from the hot rods to four steam generators by circulating carbon dioxide gas under a pressure of seven atmospheres. The steam passes to a conventional turbo-generating station and about 70 MW of electricity will be produced. We are building four of these Mark I power stations and by 1960 they should be contributing about 300 MW of electricity to the National Grid. These are

to be followed by twelve further Electricity Authority power stations which should develop up to 2,000 MW of electricity by 1965. The Government plan provides for spending about £300 million on this development by 1965. From 1965 to 1975 the construction of nuclear power stations should proceed at a much greater pace and the annual installation may well rise to 2,000 MW—requiring an annual expenditure of about £200 million.

Important new developments in industry are likely to arise from the application of high intensity short wave radiation, which is now becoming available from two sources. The first source of radiation is the electron linear accelerator which was developed by A.E.R.E. and is now being produced by industry. The mean beam power in the latest accelerator is 2 kW. The second source is from the waste products—the fission products which will automatically be produced in ton quantities from nuclear power stations within the next few years. Recently a group has been formed at the Atomic Energy Research Establishment, to investigate the possible applications of the vast amount of radiation which will become available. Already important successes have been achieved in widely different fields. Mutation of seeds has resulted in hitherto unknown variants of plants, entirely new physical properties have been achieved by the radiation of plastics, a number of products have been sterilized which are of great commercial interest and chemical changes have been stimulated which may result in development of new products.

The United States Atomic Energy Commissioner, Dr. Willard F. Libby, has estimated that, in that country, 200 million dollars could be saved per year by using radiations in the field of agriculture alone. The main part of the saving results from variants of farm products which are resistant to diseases. Soon, 600 researchers will be employed in the United States on the preservation of food by radiation. Looking a few years ahead one can foresee a great number of commercially suitable radiation applications which will either make a product considerably cheaper or better, or will be instrumental in producing entirely new products.

In this country some success has been achieved in the sterilization of hospital blankets and also in the sterilization of pharmaceuticals by gamma radiations. More recently, research work has been started on the safe sterilization of virus which is extremely difficult to achieve by orthodox methods without harming the anti-genicity of the resulting vaccine.

It is contemplated that this new Technological Irradiation Group will be the centre for the development work for many applications of ionizing radiations to industry owing to its versatility in commercial applications. This group will be diversified and will consist not only of physicists, chemists and engineers, but also of biologists, who will work closely together with other existing organizations. A number of radiation facilities are being set up. The first of these will be a powerful electron linear accelerator ; later this year there will be at least one assembly of spent fuel rods from our DIDO reactor providing a radiation source equivalent to two million grams of radium. They will also have two 10 kc sources, of which one will be cobalt 60 and the other caesium 137, and eight smaller cobalt 60 units. To allow the new group to expand it is being set up at a separate site some nine miles from Harwell. I believe that its development will make a very important contribution to industry in this country in the near future, and it may well be comparable to the power programme in its importance.

The chemical industry provides another good example of the application of science and technology. Its achievement in the production of new products such as nylons, plastics, synthetic rubber, silicones are very well known. The President of the U.S. Dupont Company in an article in *Fortune* (May, 1955) gave some very interesting figures on the growth of scientists employed by the chemical industry in the U.S. During the last twenty years they have increased from 6,500 to 35,000—they double in numbers in somewhat under ten years. The Dupont Company have good records of their expendi-

ture on research and development since 1921 and also for construction expenditure during the same period. During the whole of this period the ratio has been about one to three. That is, for every dollar spent in their research and development they have sooner or later spent three dollars for new plants, products and processes. This ratio has remained constant during a period when research expenditure has increased from 1 million dollars a year to 60 million dollars. In this country Imperial Chemical Industries Ltd. employ a research staff of 1,700 graduates and 2,800 technicians and their annual expenditure on research and development is £9 million Their expenditure on new plant, processes and products in 1955 was over £30 million. Their annual output is worth £400 million. Terylene and titanium are good examples of their recent new products.

The antibiotics and allied industry is another post-war growth which developed from the work of two or three academic scientists, particularly Sir Alexander Fleming and Sir Howard Florey in British laboratories ; followed by intensive applied research and development in the U.S. We are all now more and more indebted to the wonder drugs, penicillin, streptomycin, aureomycin and the sulphur drugs. Other important products are the anti-malarials, the insect repellants, the insecticides and selective weed killers. Compounds such as B_{12} together with antibiotics are now used in a large way in farming to promote the fattening of livestock. A single U.K. Company employs about a hundred graduate staff and a single compound such as Cortisone has cost half a million pounds to develop.

In the metallurgical industry in Britain a little over 2,000 scientists and technologists are engaged in research and development, half of these being graduates. My personal knowledge extends only to the development of the newer metals important in atomic energy—uranium, plutonium, thorium, zirconium, beryllium, niobium. We have developed methods for the extraction and fabrication of these metals with the help of industry. We have found it necessary to build pilot plants, usually with the help of industry. A typical pilot plant may cost £70,000 to construct and £50,000 per annum to operate. This must go on for a period of three or four years. It may then lead to the construction of a full scale plant with an output in the region of 100 tons per annum with an annual value of perhaps £1 million.

Research and development may easily lead to economies in extraction and fabrication of uranium amounting to between £1,000 and £2,000 a ton, so in a future nuclear power programme which demands tonnages of uranium of over 1,000 a year, savings of several million pounds a year may result from a comparatively modest research and development effort.

An interesting recent example of metallurgical research and development at Harwell has been the production of fuel elements for our new research reactor DIDO. The fuel elements consist of enriched uranium alloyed with aluminium and sheathed in aluminium sheets to prevent corrosion by the water of the reactor. Billets of the enriched uranium are first of all melted in a vacuum furnace with aluminium to form an alloy. The alloy billet is then covered with sheets of aluminium and passed through a rolling mill forming a strip of a few millimetres thickness, the sheath being automatically pressure welded on to the alloy. The resulting plates are then X-rayed to show the distribution of the alloy. They are then cut and bent to shape and a number are brazed together with channels between to form a complete fuel element.

The aircraft industry has been based very heavily on scientific research and technological development. The industry relies heavily on the Royal Aircraft Establishment at Farnborough for its basic knowledge and for the operation of very expensive facilities such as high speed wind tunnels. The annual expenditure in the industry on research and development probably approaches £100 million of which more than half is Government money. The annual intake of graduates is very high—over 200.

The extent of the trade resulting from the development of a successful aircraft is shown by the sales of the Viscounts which now exceed £100 million while the total annual export of the industry is about £100 million.

If we look at the position in other and older industries such as railways, shipbuilding and the automobile industry, science appears to play a much smaller role. In a recent report of the Government's Committee on Scientific Man Power it is stated that three shipbuilding firms recruited no graduates but over 200 apprentices; five motor firms recruited thirteen science graduates and 270 apprentices. The annual expenditure on research and development of railways, shipbuilding and automobiles is £350,000, £200,000 and £3 million respectively. These lower figures are characteristic of industries relying very much on traditional methods changing only by small steps from one model to the next. They prefer to recruit their technicians and technologists at 16 or 17 and bring them up the way of the shop floor and the local technical college.

EXPENDITURE AND MANPOWER DEVOTED TO RESEARCH AND DEVELOPMENT IN U.K.

If we now look at the overall picture there are a number of important questions which might be asked. First of all, how does our total expenditure on research and development compare with our most important competitor—the United States ?

Exact figures for total expenditure and scientific manpower engaged in research are difficult to obtain. Government expenditure on scientific research and development in 1956-57 has been estimated at about £235 million. Research expenditure by industry for its own purposes is probably over £40 million. This compares with an expenditure in the United States of about 5 billion dollars. If we take the " real value " of the dollar to be five to the pound this means that the United States are spending about four or five times as much as we are on research and development so that the per capita expenditure is not very different. They have a rather greater ratio, of about six to one, in the number of graduate scientists and technologists in the working populations.

We might next inquire how this expenditure is divided between fundamental research, civil applied research and defence research. Exact figures are not available but our research expenditure is probably divided roughly as follows :—

	expenditure	*graduates engaged*
Fundamental research. Universities	... £5 ± 2 million	4,000
Fundamental research. Government and semi-government	... £5 ± 1 million	1,000
Civil applied research	over £60 million	40,000
Defence research	about £200 million	

It seems then that expenditure on fundamental research is less than 5% of the total and the numbers engaged on fundamental research are about 10% of the total graduates engaged on research. The corresponding U.S. proportion of expenditure is 7%. We do *not* therefore seem to be devoting too much of our effort to the basic research from which all applied research springs.

THE EDUCATION OF SCIENTISTS AND TECHNOLOGISTS

We might ask ourselves next how the demand for scientists and technologists is likely to grow during the next ten years. The Committee on Scientific Manpower recently reported that Industry is at present only getting about 75% of the graduates it needs. There are also large shortages of graduate science teachers in the schools. The Committee is enquiring now into the probable increase of demand for graduate scientists and technologists in the next decade and its report will certainly be awaited with interest. In the meantime it is interesting to note a forecast made by the President of M.I.T. in his recent annual address. He predicted that the requirements for scientists and technologists in the United States would double again in the next decade—as it has doubled during the previous two decades. A similar forecast for their own needs has been made by two of the largest employers of scientists and technologists in Britain. These forecasts seem to be very reasonable in view of the increasing complexity of the newer industrial developments.

What sort of training will this next generation of applied scientists require. I will again quote from the President of M.I.T.'s address. " As our advancing

technology becomes more complex and sophisticated it requires scientists and engineers and managers of more advanced education and analytical powers. There are areas of technology so new and rapidly advancing that only men with self-acquired fundamental and versatile understanding or with recent education in the new technologies are able to master and keep pace with them. Employers want more scientists and engineers but they don't feel that they are meeting the need by employing inferior or narrowly educated ones. They want men, particularly young engineers, with the power to deal with the technologies of tomorrow and not to-day or yesterday."

These views have been strongly supported by Dr. Mervyn Kelly, Director of the Bell Telephone Laboratories of New York, the largest scientific and technological institute in the world, in a recent informal talk in this country. Dr. Kelly feels the education of engineers must in future have a higher scientific background. My own experience of atomic energy development has shown that our rapid advances have been made possible by the high scientific and technical quality of our graduate staff backed by the support of equal numbers of technicians.

We must also see to it that our young engineers and scientists are educated in an environment which will produce the future leaders of industry. Leadership requires not only good technical knowledge and judgement but the personal qualities which inspire others. In my view the best way to achieve this is first to maintain a good standard of general education up to and including the sixth form level and then for students to live for at least part of their university life in colleges or halls of residence where all the faculties of a university are mixed. The clubs and societies of the undergraduate world are the best form of general education at that period of life.

Let us now look at our achievements in producing technologists. Our annual output of graduate technologists is at present about 2,800 and of scientists about 5,200. The 2,800 graduate engineers compares with an output of 23,000 in the United States and 53,000 in Russia. So Russia is now turning out about eighteen times our number of graduate engineers and about ten times our number of scientists. The training of the Russian graduates in science is severe—they receive 5,800 hours of full time instruction in a course of five and a half years—so they are fully equivalent to our graduates.

At a lower level the U.S.S.R. produces about 78,000 technicians from the *Technicums*—these compare with our 9,000 a year Higher National Certificate and Diploma students. The Russians have given good evidence of their capacity in the fields of atomic energy and jet aircraft as well as in academic studies in the most important fields of modern physics. The power of the U.S.S.R. in a world where military power is stalemated may well in future depend more on its big battalions of technologists than the classical methods of power politics.

What are we doing to improve our relative position ? The recent Government White Paper (Cmd. 9703) has stated that it is the intention of the Government to expand still further the provision for technological education in universities. I would like to express a personal hope that it will be possible to double the number of university graduates in technology during the next decade.

The Government is also to spend £100 million in expanding and improving twenty-four regional colleges to enable them to organize sandwich courses of instruction over a period of five years. This course will lead to a new award—" the Hives award." It is hoped that these arrangements will enable the stream of good talent amongst the " early school leavers " to be tapped. The White Paper hopes that it will be possible to produce an additional 2,500 technologists a year in this way.

By 1962 the birthrate bulge will increase the number of children of college age by 40% ; there is also evidence of an increasing proportion of sixth form students and university entrants taking science. If we take advantage of all these factors there is a good chance of providing the additional scientists and technologists we need.

Albert Einstein*

By Professor E. FINLAY-FREUNDLICH, M.A., Dr.Phil.

(*University of St. Andrews*)

DURING the fifty years which have passed since Einstein started his research which should revolutionize the principles on which natural philosophy had been based, a vast amount of literature has developed, and it has thus become difficult to work out clearly what is Einstein's own and quite original contribution to this development. The extensive discussion of the cosmological problem in particular has diverted for more than 20 years the focus of interest to this problem, as if it were the essential point of the general theory of relativity. We are therefore justified to go back to the early years of Einstein's research when his fundamentally new ideas took shape.

Happily, we have a document from Einstein's hand which outlines clearly the various stages by which he advanced and finally was led to the creation of the general theory of relativity and later on to the unified field theory.

Very soon after the end of the first World War when Einstein's fame began to spread—chiefly on account of the success of the solar eclipse expedition in 1919, which safely established the existence of a light deflection in the Sun's gravitational field, seemingly in accordance with Einstein's prediction—the writer of this article received a letter from England asking for details concerning Einstein's life and scientific career up to, say, 1920. Einstein, who happened to be present when this letter arrived, took a piece of paper, noted down the main data of his life and academic career and concluded this short account with the following words which are in verbatim translation from German :—

" The dates of my most important scientific ideas are :—

1905 : quantum law of emission and absorption of light, theory of Brownian motion, restricted theory of relativity; inertia of energy ;

1907 : fundamental ideas on general theory of relativity ;

1912 : realization of non-Euclidian nature of metric and its physical dependence on gravitation ;

1915 : the field equations of gravitation ; explanation of the advance of Mercury's perihelium."

This short spontaneous report is in many respects of particular interest, partly (naturally) on account of its actual content, but partly also on account of what Einstein does not mention. I shall use this short note of Einstein's as our guide on the way which he took when he created the general theory of relativity.

Perhaps the most astonishing and impressive fact is the entry for the year 1905, when Einstein was 26 years of age. It is, I believe, unique in the history of science that a young scientist in the very beginning of his activity should publish three scientific papers in rapid succession—the dates of their presentation are the 18th of March, the 11th of May and the 30th of June, 1905—papers concerning very different branches of physics, each of which has become a fundamental contribution to—if not the foundation—for a quite new development of science.

The first paper on the quantum law of emission and absorption of light has become

* A lecture given to the Scottish Branch of the Institute on November 11 and 28, 1955

the starting point for the photon theory of light.

Einstein made many further contributions of fundamental importance to this theory after 1905—only to mention his photochemical law of equivalence in 1912 and his new derivation of Planck's law of radiation in 1917. It is therefore surprising that he did not consider these contributions worth mentioning when he wrote down this short report on his work. This omission reflects, however, to a certain amount the fact that around 1920 his mind was completely absorbed by his violent struggle for the creation of a general theory of relativity in which he stood quite alone ; partly, however, it also may reflect his growing alienation from the development which the quantum theory was beginning to take.

It is also of considerable importance to point out that for 1905 Einstein claims the creation of the restricted theory of relativity as his own personal achievement.

I believe there is no doubt that this claim is fully justified despite the fact that Poincaré and Lorentz had already derived many results of the restricted theory of relativity before Einstein started his research in 1905. Despite also the fact that some of the ideas which Einstein later incorporated in his general theory of relativity had been pronounced by others long before his theory had crystallized, his name will always be remembered as that of the creator of the theory of relativity. For he made this theory the foundation from which all fundamental concepts concerning space and time in physics have to be shaped.

It is, for instance, true that Lorentz's transformation formula of the time variable—reflecting a transition from one system of reference to another one, which is moving relative to the former with constant speed—was known already to Woldemar Voigt (Göttingen) as far back as 1887. But while Lorentz interpreted the " transformed " time variable as an " auxiliary variable " which he named " local time," it was Einstein's much deeper searching mind which revealed the relativity of all time measurements and thus made necessary a complete revision of our ideas concerning the geometry of space and time.

The importance of Einstein's contribution to the restricted theory of relativity lies in the fact that with relentless logic and courage he drew all the conclusions which follow from Lorentz transformation formulae, even if they upset the foundations of existing Natural Philosophy.

The transformed time-variable is not, as Lorentz maintained, just an auxiliary variable, called the local time, but it is the time in the moving system and reveals the relativity of all time measurements.

This was a complete break with the traditional view taken, for instance, in Kant's philosophy, as to the *a priori* character of space and time measurements.

By basing all phenomena of kinematics, covering all motions with constant velocities, including also all electromagnetic phenomena on a new, closed and consistent set of concepts which is to-day called the restricted theory of relativity, Einstein made an inroad into Newton's theory of motion that could not be simply patched up, in order to align classical dynamics to the restricted theory of relativity.

This is important to know in order to understand the heading under 1907 which does not refer to any concrete published results. After the first violent opposition to Einstein's restricted theory of relativity had died down with the realization that the new theory was in itself consistent and in agreement with all empirical facts, attempts were made from various sides to adapt Newton's dynamics to the restricted theory of relativity. It was left to Einstein to show that such an adaptation is not possible.

The set of concepts on which the restricted theory of relativity rests is a fundamentally different set from that on which Newton's theory of motion rests ; and new concepts were required to extend the restricted theory of relativity to include accelerated motions which characterize all phenomena of dynamics in Newton's theory.

In the restricted theory of relativity, the relativity of motion is confined to motions with constant straightline velocities. For, as soon as accelerations or deviations from the straightline motion appear, forces make their appearance. These forces do not reveal any other specification than that of depending on one single property of the moving body, called its inertial mass : m_i.

Since no localization, i.e. causal connection to any observable outside agency, appeared to be possible, absolute space relative to which the body was considered to be moving, was made responsible for the appearance of these fictitious forces called inertial forces.

If no forces make their appearance the body will move with constant speed along a straight line ; and since the straight line is the shortest path between two points in Euclidian space, and since it was taken for granted that Euclidian metric conditions prevail in physical space, the law of inertia in Newton's theory of motion could be formulated as

$$\delta \int ds = 0$$

where ds is the line element in Euclidian geometry :

$$ds^2 = dx^2 + dy^2 + dz^2$$

This state of affairs was unsatisfactory. For the concept of absolute space as a physical quantity is not really clearly defined ; the assumption of a body moving without any outside force whatsoever acting upon it—on this assumption the just mentioned law of inertia is based—is unrealistic, because all bodies in the Universe are mutually linked together by the universal force of gravitation.

Moreover, an obviously deep relationship exists between inertial and gravitational forces ; this is revealed in nature by the fact that the gravitational action of every body is characterized by one specific property of the body called its gravitational mass m_g and this gravitational mass m_g is, as experiments have shown, strictly equal to the inertial mass m_i for every body.

Hence Einstein's entry for 1907 means that he began to realize that the equality of inertial and gravitational mass is of fundamental significance for opening up the way to a general theory of relativity. In Newton's theory this equality had remained not understood and unexplained, a mere chance coincidence.

The equality of m_i and m_g can be incorporated into a new set of fundamental concepts comparable with those on which the restricted theory of relativity had been based by formulating the principle of equivalence. This principle states : *every change which any physical phenomenon reveals under the influence of a gravitational field, it would also reveal if, in the absence of any gravitational field, the phenomenon were studied with reference to a system of coordinates moving with the acceleration that had been characteristic of the gravitational force in the first case.*

All gravitational problems thus merge into a general theory of motion including all accelerated motions. Such a principle can be formulated, because inertial forces, which appear as soon as bodies are accelerated, are indistinguishable from gravitational forces ; and this again is empirically proved by the fact that all bodies fall in the gravitational field of the earth with the same acceleration—or, in other words, because the inertial mass is strictly equal to the gravitational mass for every body.

The principle of equivalence links thus the general theory of relativity to safely established empirical facts. This is the fundamental feature of Einstein's theory. It has sometimes been lost from sight during the last years ; in its stead the point is frequently stressed that the equations of motion can be formulated in a general covariant form. This latter fact is not the essential feature from the physical point of view ; the pivot of the theory is the principle of equivalence.

The restricted theory is thus widened so that also accelerations are comprised in a general theory of relativity.

This is what Einstein envisaged as early as 1907. What he obviously at that time did not realize was : which sacrifices with regard to existing principles would have to be made in order to establish a general theory of relativity.

Apparently it was in 1912 when he first realized that after the absolute character of time measurements had been given up, also the *a priori*, absolute character of Euclidian geometry would have to be abandoned to achieve a general theory of relativity. To understand why this is unavoidable let us go back to Newton's kinematics, in particular to his law of inertia.

In Newton's, as well as in the restricted principle of relativity only such systems of reference are equivalent which move relative to each other with constant velocity. The path along which any mass moves, not subject to any external force, is the geodetic given by the equation :—

$$\delta \int ds = 0$$

$$ds^2 = dx^2 + dy^2 + dz^2 \; ;$$

the latter expression remaining invariant with regard to Lorentz transformations.

In a general theory of relativity all systems of reference claim to be equivalent ; for all observations reveal only relative motions of bodies. The principle of equivalence states the complete equivalence between inertial and gravitational forces. Since, however, the concept of a gravitational force acting between widely separated bodies has always produced doubts and criticisms, it appears advisable to drop the concept of force completely and to extend kinematics in such a way that it covers also all accelerated motions.

Newton's law of inertia claiming that any mass not subject to outside forces moves along a geodetic might then remain valid and become the general law of motion, also with regard to accelerations, if the line element ds is given a more general expression which remains invariant, also with regard to transformations expressing arbitrary accelerations. This necessitates the introduction of Non-Euclidian or Riemanian metric into physical space and time ; this again necessitates the identification of the functions $g_{\mu\nu}$ which enter into the general expression of the line element :—

$$ds^2 = \sum_{1}^{4} g_{\mu\nu}\, dx_\mu\, dx_\nu$$

with the " potentials " of the gravitational field responsible for the acceleration in question. The ten functions $g_{\mu\nu}$ replace the one gravitational potential in Newton's theory of motion ; they determine the gravitational field. Thus the gravitational field for any chosen values of the four co-ordinates—they have now more the character of parameters—is characterized by the deviation from the Euclidian metric of the four-dimensional physical space-time manifold. Gravitation obtains a central position, that of defining the geometry of the physical space-time manifold. In Newton's law of motion the gravitational force figures only as one of the many possible forces that may give rise to an acceleration of a moving body.

Without knowing it at the time when he created the general theory of relativity, Einstein had solved a problem which Riemann had proclaimed many years before in 1854. In his investigation : " On the hypotheses which underlie geometry " Riemann had shown that the metrical conditions of a continuous manifold, like that of space and time, are not given *a priori*, but are determined by " binding forces " ; these, according to Riemann, have to be discovered by studying the motion of bodies in space. Einstein had never heard of Riemann's results and was startled when I read to him the conclusions reached by Riemann. Einstein's discovery meant that gravitation may be interpreted as the " binding force " which determines the geometry in the four-dimensional physical space-time manifold.

At that time, 40 years ago, only very few were willing to sacrifice the privileged position of Euclid's geometry, and Einstein at first met with great scepticism if not open opposition. He himself was so far ahead of the ideas that had come down from the past that he wrote in a letter commenting on Nordström's theory of gravitation : " but also this theory is based on the *a priori* Euclidian four-dimensional space in which to believe appears to me more or less a superstition."

After he had freed himself from this " superstition " it took him a few more years before he was able to formulate the differential equations which connect the functions $g_{\mu\nu}$, the ten coefficients of the general Riemanian line-element, with the physical

quantities, i.e. the distribution of gravitating masses and energy which produce the gravitational field, and thus really establish gravitation as the "binding force," defining the metrical conditions of space.

The theory had to prove its mettle by yielding the right laws of planetary motion; it did more.

The law of motion, in its new form $\delta \int ds = 0$ in which ds is the line element for a non-Euclidian four-dimensional space-time, claims that a planet moving in the gravitational field of the Sun, must move along the shortest line connecting a point A of the orbit with an arbitrary other point B; that means the orbit is a geodetic. Since the geometry is no longer Euclidian this geodetic is no longer a straight line, but a curve. It was truly a triumph for Einstein when he was able to show that the Kepler ellipse, with additional small corrections, really resulted as the geodetic in the gravitational field surrounding a stationary, symmetrical, large gravitating mass like the Sun. In his solution of the problem the planet was assumed to be so small that its own contributions to the gravitational field may be disregarded. The small additional correction, just mentioned, accounts exactly for the anomaly, in the motion of the planet Mercury nearest the Sun, which had remained unexplained within Newton's theory of motion. This result Einstein achieved in 1915. Moreover, since Einstein had discovered the inertia of energy as far back as 1905, the principle of equivalence demands that energy too must be subject to gravitation. A light beam passing near to the Sun should therefore be deflected by a measurable amount. The first successful experiment to prove this conclusion confirmed this prediction. However, it may not be overlooked that the extension of the law of motion to moving photons comprises certain hypotheses concerning the physical nature of photons which are not yet safely established. Thus a final test of the general theory of relativity has not yet been achieved.

The fundamental character of gravitation which permitted its geometrization made it imperative that cosmological considerations, concerning the metric structure of the Universe as a whole, had to be taken up. For already in the simplest case, i.e. the motion of Mercury around the Sun—even if it is solved under very simplifying assumptions, considering the mass of Mercury as infinitesimally small compared with that of the Sun—definite assumptions have to be made about the value which the line-element of space and time, i.e. the gravitational field, approaches in the limit at an infinite distance from the Sun. Otherwise no defined solution is obtained. The solution obtained was based on the assumption that at infinity the line-element approaches the value for a gravitation-free space-time manifold on which the special theory of relativity rests. This, however, implies very definite assumptions concerning the distribution of matter throughout the Universe. It means, namely, that all observable celestial bodies must be surrounded by empty space extending to infinity. In the general theory of relativity based on the geometrization of gravitation, the cosmological problem becomes thus a problem of primary importance.

Realizing how unsatisfactory the assumption was which had to be made in solving the problem of Mercury's anomaly of motion, Einstein set himself the task of extending the general theory of relativity to include the cosmological problem. It was in the course of this problem that in 1917 he made a discovery of outstanding importance.

Einstein was particularly proud that he had been able to complete the general theory of relativity without having to introduce any new physical constant. The gravitational constant and the value of the velocity of light are the only constants which enter into his theory. However, when extending the considerations to the whole Universe, he found that the introduction of a new, the cosmological, constant offered the possibility of removing the fundamental difficulties that arise when a theory of gravitation is extended to the Universe as a whole.

A permissible generalization of his field equations, including this new cosmological constant, offers, if the masses constituting the Universe are uniformly distributed and if

they are considered at rest—that means having velocities small compared to that of light—a solution in which space attains the character of a closed space of finite radius, constant positive curvature and finite volume. The problem of infinity resolves itself; no assumption about infinitely distant masses, no infinite amount of mass and energy constituting the whole Universe, have to be considered. The gravitational field, arising from the masses, endows the Universe as a whole with the structure of a closed, unbounded, finite space. Speculations on whether the Universe was finite or infinite which had existed since the conception of non-Euclidian geometries but which had been lacking substance because no connection existed between the laws of physics and the metrical properties of space, were brought into line with a sound physical theory of gravitation.

This prize appeared to Einstein important enough to justify the introduction of a new special constant, the cosmological constant, whose influence only begins to be of importance when the dimensions of the whole Universe are taken into consideration.

With this discovery Einstein burst a dam which led to a veritable flood of cosmological theories. Simultaneously with Einstein's discovery, astronomers discovered the general red-shift in the spectra of extra-galactic nebulae, which, interpreted as a Doppler effect, indicated a general expansion of the Universe. In addition, it was shown that Einstein's static and finite Universe would not be stable; it represented merely a special case within an infinite multitude of imaginable expanding or contracting, finite or infinite Universes. Einstein, averse to all vague speculations, and realizing that the introduction of the new cosmological constant might obscure the sound foundations of his theory of relativity, abandoned the *ad hoc* hypothesis of a cosmological constant and preferred to leave the cosmological problem in suspense.

This probably explains the surprising fact that Einstein makes no mention of his research on the cosmological problem in his biographic notes from which we started, although he had reached his fundamentally important result that the Universe might be closed and finite only shortly before he wrote down his short report.

After 1920, Einstein shifted his main interest toward the extension of the general theory of relativity to a unified field theory comprising also the electromagnetic phenomena into the frame of the "binding forces" defining the metric condition of the space-time manifold. Parallel to this development ran the development of modern quantum theory, differing in many respects fundamentally from the principles which Einstein hoped to use as the foundation of physics. This deepening gap, separating two main branches of physics, has been the tragic feature in Einstein's scientific life. More than any other, since Newton, he had strived to unify the principles of physics. His unifying ideas have opened up a new phase in the history of exact natural science and will be of lasting importance.

The General Certificate of Education Advanced Level Examinations as Criteria for University Selection*

By MISS K. E. PARKS, B.Sc., A.Inst.P.

(*North London Collegiate School*)

THE INSTITUTE OF PHYSICS, in its publication "The Availability of Places for Physics Students in Universities and Technical Colleges," says that a disturbing proportion, probably of the order of one-third, of those accepted do not complete the honours course. It also says that it is unfortunate that the examination results for the General Certificate of Education and the reports from headmasters do not provide an adequate basis upon which the universities can make a satisfactory selection, but that the responsibility lies with the universities to devise a more effective system of selection ; further that there is wide agreement among university teachers that the results of the Advanced Level examination are becoming less reliable as an indication of real ability in a subject.

Any remedy suggested for the solution of the problem of adequate selection must take into account the difficulties of the schools as well as those of the universities. We have in our classes for Advanced Physics, in the majority of schools in the country, many pupils who need an Advanced Level qualification who are not intending to read Honours Physics or even to go to the university at all. In a typical year in my school, among a class of twenty pupils, just over one-third would be going to the university to read for degrees in Mathematics, Physics, Chemistry, Botany, Zoology or Pharmacy, just under one-third to read Medicine or Dentistry and the last group would be made up of would-be laboratory technicians, nurses, training college students, civil servants, farmers, radio- and physio-therapists and teachers of physical education. Of these, only the ones wishing to read Mathematics, Physics and Chemistry at the university will be doing Mathematics to the Advanced Level.

Some of the non-honours graduate group will be studying Physics because they need it as a qualification, and some from choice because they enjoy the subject. We must not, in our effort to do justice to the honours Physics candidate, make the course so exacting that a pass in the examination is out of these pupils' reach. When Sir Philip Morris inaugurated this Education Group of The Institute of Physics, he made a plea for a varied approach to the teaching of Physics in grammar schools if all boys and girls are to have some reasonable understanding of the prevailing interpretation of the physical universe. Desirable though we recognize this to be, we must keep our feet on the ground and cut our coat according to our cloth. With the present, and future shortage of science teachers, there seems little hope of a multiplicity of classes in Physics taking the place of the present omnibus one.

An obvious solution to the present difficulty in selection is for the faculties or colleges to set their own entrance examinations. These are already on the increase and there is what seems to me to be a justifiable outcry from the schools against it. Where schools do not

* An address given to the Education Group of the Institute on April 6, 1956

specialize early, the examination usually comes after only four terms of advanced work, when the candidate must of necessity be ill-prepared for it and feel unable to do himself or herself justice. Speaking for girls' schools, we have to provide invigilation, have a sixth form class room out of action, and teach depleted classes, from November till Easter. Some disadvantages of this are obvious, but not so obvious is the fact that it produces an atmosphere of strain and disquiet in the whole group.

A more profitable line of approach might be to look critically at the Advanced Level syllabus and examination questions and ask if the syllabuses provide as good a preparation as possible for a university course, both as regards factual knowledge and training in thinking, and if the questions set are as efficient as they might be as an instrument of selection, all the while bearing in mind that the General Certificate of Education was designed specifically for none of these purposes—the circular merely says that the examination provides a " convenient " means of securing exemption from university entrance requirements—and also bearing in mind that many besides potential honours graduates are concerned with the examination.

I have consulted teachers of wide experience with each of the examining boards and, to the question " Is passing the Advanced Level examination an indication of a proper preparation for an honours course in Physics?" the following is a representative selection of the comments made in qualifying the answers. " Candidates are required to study too many topics in the five and a half terms available." " The course can easily develop into a cramming course because of lack of time." " It is possible to pass by sheer mechanical learning." " They have no time to advance at their own pace and to find things out for themselves." " Good teaching will make them pass." " If they specialize early enough, almost anyone can acquire the necessary facility for answering the questions set." I may say that the teachers concerned with some examining boards are much more satisfied than others.

May I pause for a moment here and refer to the report of the Vice-Chancellors Sub-Committee on University Entrance Requirements. I was struck by the absence of any reference to " attitude of learning." They are worried about evidence of " general education," some even recommending an examination in the subject, but they never seem to want to find out if the candidate has an alert and inquiring mind, or if he is merely a passive collector of information ; if he has some initiative in trying out things for himself. If I may quote from A. N. Whitehead: " Though knowledge is one chief aim of intellectual education, there is another ingredient, vaguer but greater, and more dominating in its importance. The ancients called it wisdom. You cannot be wise without some basis of knowledge, but you may easily acquire knowledge and remain bare of wisdom. Wisdom is the way in which knowledge is held. It concerns the handling of knowledge, its selection for the determination of relevant issues, and its employment to add to our immediate experience."

I also asked the question " Is the Advanced Level Examination a suitable one for indicating future performance ? " Some people thought it was if the pass was at a high enough level, but there was a general appreciation of the other factors involved. How will the student react in a different environment, the change from life in a community of younger, to life in a community of older people ? It may be the first time he has lived away from home, and what about the effect of that home ? How will he adapt himself and his work to the new social demands ? Will he be left to sink or swim, or will there be someone who takes an individual interest in his welfare ? Will all his lecturers be conscious of good teaching techniques ? There is no doubt that the majority of students would make a far better showing at the university if given wise guidance in matters outside their academic course, for, after all, they are young human beings beginning their lives in a specialized adult world. In former days, such help was probably assimilated unconsciously from the home background, but now that we are making efforts to find and develop all the

potentialities in the nation, we must recognize that there are important new problems which must be dealt with effectively if our other efforts are not to be made in vain. Parents, however willing, may find the problems quite incomprehensible for they are problems quite outside their own experience. Where there is no tradition of learning in the home there can be no conception of the discipline involved in a life of study. There is a real need for an effective tutorial system in every university.

This question also brought some comments on the scholarship paper, which was thought to be of value in those cases where it contains questions requiring a deeper knowledge and appreciation of the Advanced Level syllabus, but of very little value when it is made up of relatively easy questions on an extended syllabus. Also, where the scholarship paper makes use of an extended syllabus, and the class is one of mixed interest and ability, good candidates for Physics Honours are sometimes lost to Mathematics, where the group is much more highly selected and usually about one-third of the size. This smaller selected group can cover the wider syllabus, but the large unselected Physics group cannot. Its best members, however, could easily deal with questions requiring more thought and understanding of the syllabus than is needed to answer the ordinary Advanced Level questions, and hence show their calibre and also have their interest stimulated and maintained.

And now for definite suggestions :— first of all to get rid of this sense of rush in the examination at Advanced Level. The candidates should not be asked to answer more than five questions in three hours, so that there is some chance to stop and think, and some chance of producing a well-knit and reasoned answer. And secondly, to get rid of the sense of rush in the two years' work in the sixth form, can we not have a reduction in the syllabus, so that we have time to explore a few byways, to take stock of the knowledge that has been gained and to try and see it in relation to other knowledge, to get some idea that knowledge is a unity and not a mere collection of unrelated scraps ? I am sure that this kind of treatment of a syllabus would give a much more worthwhile general education than a lesson or two a week in " unrelated " subjects, and would benefit those who are not going to the university as well as those who are. They all need time for consolidation if they are to attain an all-round maturity. Surely it is better for students to go up to the university with a foundation of good habits of learning than to arrive stuffed with undigested knowledge.

To help with the selection for university entrance I would suggest that each candidate be required, at the time of his Advanced Level examination, to write an essay on a topic connected with his main subject, one which, while it has as its basis known facts, requires a little individual thinking and a little imaginative use of knowledge. Some co-operation between different colleges and universities would be needed so that the essay should be available to any college considering the admission of the student, but the " clearing house " seems to work quite well for the admission of students to training colleges, and there seems no reason why in a modified form it should not work for university entrance. A large proportion of students do not know now if they have a place until after the Advanced Level results are published, and so this innovation should not make any difficulties regarding timing.

It would, I think, also be helpful if all universities had a General Honours course, so that there is some level between an ordinary or Pass degree and an Honours degree in a single subject. Then I would suggest that students are not accepted for a special Honours school until after one year at the university. They could share a common training, and take their first year quietly and steadily while getting used to everything new. They would also have an incentive and the whole atmosphere would be more constructive than the down-grading or rejection which takes place at the moment. During that year, each Honours school would have an opportunity of getting to know their candidates at first hand.

To sum up, there seems to be a number of possibilities which might be tried within the

present framework for improving the adequacy of university selection. In our anxiety to meet the present demands for more scientists and technologists, we must not forget that schools and universities are primarily places of learning, places for the education of the whole person, and not training grounds for specialists.

We owe it to all young people not to let them think that the predominant spirit in a scientific age is superficial and materialistic but to make them aware of the wealth of imaginative and creative thought which accompanies it. We may perhaps save them from the materialism which seems to be engulfing us as a nation.

Correspondence

The interesting article by Prof. Gavin in the April *Bulletin* inspires me to draw the attention of Members of the Institute to a matter which has been causing me increasing concern during the past few years.

It is well known that certain universities do not teach or examine in all faculties ; but, subject to this obvious limitation, it seems to me that it should be axiomatic that an M.Sc. or Ph.D. candidate should not be penalized because the subject of his proposed thesis falls between two Chairs. If a candidate presents a thesis of sufficiently high standard, adequately written, the question as to which department is most suitable for his registration should be settled as a matter of administration only.

In some universities, this principle is accepted without question ; in others, in my recent experience, the unfortunate candidate is shuttled about till he reaches what is supposed to be a suitable department, and then told to change the subject-matter of his intended research to suit the personal whim of some examiner.

This policy is especially unfair to candidates who are in full-time employment. The director of research will, no doubt, make every effort to allow the candidate to pursue a subject suitable for a higher degree thesis over the necessary period of time. Sometimes this is not possible. But, when it can be arranged, it is most unfair if the candidate is then told that he must alter his programme " to investigate the electrical rather than the thermal properties of his materials " or that " it would be better to study materials with higher melting points." It is seldom the case that the proposed changes would make the investigation any more suited to the requirements for a higher degree.

May I ask Members who are in a position to do so, to use their influence to ensure that the scope of our universities should be as " universal " as is possible ; and that neither purely administrative questions, nor the idiosyncrasies of examiners, should be allowed to penalize good candidates for higher degrees ?

G. W. Scott Blair.

The National Institute for Research in Dairying,
Shinfield, Reading.

Branch and Group News

South Wales Branch

The one-day conference on Physics in Industry arranged by the South Wales Branch of the Institute at Cardiff on April 13 was the focus of considerable interest. Members of the conference were particularly happy to have the opportunity of welcoming the President of the Institute, Sir John Cockcroft, who delivered a public lecture in the evening on " Science and technology in industry," published in this issue of the *Bulletin*. The conference attracted a large attendance, both of members of the Institute and of the scientific staffs of the various industries established in the area.

From left to right : Dr. G. Williams, Sir John Cockcroft, Mr. R. W. White, Mr. R. G. Wood and Dr. M. R. Hopkins.

The morning and afternoon sessions were held at the University College of South Wales and Monmouthshire, while the evening lecture was given at the Reardon Smith Lecture Theatre of the National Museum of Wales. In the morning, Professor A. Porter of Imperial College spoke on " The Application of computors in the control of processes." He discussed the development of analogue computors, such as the differential analyser, and also of modern high speed digital computors. He gave a broad survey of the ways in which computors and computing units could be used in industrial applications, showing how some of these applications depended on the fact that the digital computor is designed to carry out the basic operations of symbolic logic. The discussion which followed showed that present and potential users of automatic digital computors are keenly interested in the wide range of problems which can be solved in

From left to right : Dr. H. R. Lang, Mr. A. Whitaker, Prof. A. J. C. Wilson and Mr. R. G. Wood.

Dr. A. Harvey, left, and Dr. R. O. Jones.

Sir John and Lady Cockcroft with Mr. R. G. Wood.

this way. In the afternoon, Mr. J. L. Putman, Head of the Physics Department of the Isotopes Division at Harwell, in a lecture on " Radioisotope techniques in industry and applied research " showed how important and widespread the uses of isotopes, both as sources of radiation and as tracers, had become. The availability of a large selection of radioactive isotopes is one of the most important results of work on atomic energy. It enables a choice of an element with properties suitable for a particular application to be made. It became evident in discussion that many members of the conference had problems closely related to one or another of the large number described by Mr. Putman. Mr. A. Whitaker, Director of Extramural Research of the National Coal Board, gave the second afternoon lecture on the subject " Physical Properties of Coal." This was of great interest, not only to those whose scientific work is directly connected with coal, but to others, who were given a survey of a fascinating field in which much had been achieved. In the discussion, Mr. Whitaker indicated that there were still problems which awaited solution.

Sir John Cockcroft in his evening lecture again mentioned the three main topics which had been discussed during the day—computors, isotopes and fuel. He gave a valuable account of the progress which has and is being made in the industrial use of atomic energy in this country.

The choice of subject matter by each lecturer covered admirably the industrial interests of South Wales, where besides the traditional heavy industries of coal, steel and oil, there are numerous light industries engaged in the manufacture of specialized products. Even in the traditional industries, traditional methods are being replaced at a rapidly increasing rate by a regime of modern automatic devices and scientific control.

It is felt that the conference has served many useful purposes. As usual, not the least of these was to provide an opportunity for physicists, other scientists and industrialists to meet informally and discuss matters of common interest and concern. It was an enjoyable occasion.

M. R. Hopkins.

Stress Analysis Group

A small party of members of the Group visited the Dunlop Research Centre on April 10, 1956. The members shown on the photograph are :—Front row (left to right) : Mr. W. H. Ray, Dr. E. Markland, Mr. R. G. Braithwaite, Miss M. Clutterbuck, Mr. B. Sugarman, Mr. L. Brooke Edwards ; Back row (left to right) : Dr. J. W. Illingworth, Mr. E. Gough, Mr. C. J. Ames, Mr. H. Fessler and Mr. R. P. Lawson. Behind Mr. Fessler is a member of staff of the Dunlop Research Centre.

Thirty-sixth Annual General Meeting

Notice is hereby given that the Thirty-sixth Annual General Meeting of The Institute of Physics will be held at 5 p.m. on Monday, July 16, 1956, in the Institute's House, 47 Belgrave Square, London, S.W.1. Attendance is limited to Fellows and Associates of the Institute. The business to be conducted is the consideration of the Board's report, the accounts and balance sheets for 1955, the declaration of the election of the Honorary Officers and other members of the Board nominated, and the election of auditors. A copy of the annual report and accounts was printed in the April issue of the *Bulletin*. Further copies will be sent on request.

B. P. DUDDING,
Honorary Secretary.

June 10, 1956.

Ballot papers for the election of Officers and members of the Board and for the election of an Honorary Fellow will be circulated later.

The Register

ELECTIONS TO MEMBERSHIP

THE FOLLOWING ELECTIONS WERE MADE BY THE BOARD ON MAY 15, 1956

An asterisk (*) indicates transfer from another grade

FELLOWS

Billig, Ernest, Dr. rer. tech., Head of Solid State Physics Section, A.E.I., Research Laboratory, Aldermaston, Berkshire.

*Cochran, William, B.Sc., Ph.D., Lecturer in Physics, University of Cambridge.

*Cohen, Louis, B.Sc., Ph.D., Senior Research Officer, Simon-Carves Ltd., Stockport.

Deo, Purushottam Gajanan, M.Sc., D.Sc., Ph.D., Physics Department, Royal Holloway College, London.

*Gould, John Edward, B.Sc., Director of Research, Permanent Magnet Association, Sheffield.

*McCleery, David Kirk, M.Sc., Senior Lecturer in Electrical Engineering, College of Technology, Manchester.

*Nightingale, Alfred, M.A., Lecturer, Guy's Hospital Medical School, London.

Nightingale, Ernest, M.Sc., Formerly Senior Science Master, St. Albans School, Herts.

*Schiller, Kenneth Kurt, D.Phil., Senior Physicist, The British Plaster Board Co. Ltd., East Leake, Leics.

*Townsend, Malcolm William, B.A., Head of Weaving Department, Wool Industries Research Association, Headingly, Leeds.

*Webb, Charles George, B.Sc., Head of Physics Department, University of Malaya, Singapore.

ASSOCIATES

Adlington, Raymond Ernest, B.Sc., Research Physicist, Marconi's Wireless Telegraph Co. Ltd., Chelmsford, Essex.

*Ashton, Thomas, B.Sc., Clinical Physicist, Cookridge Hospital, Leeds.

Axe, Roy, B.Sc., Deputy to Manager, Fundamental and Process Physics Section, Dunlop Rubber Co. Ltd., Birmingham.

*Barker, Keith Homer, B.Sc., Ph.D., Lecturer, Imperial College of Science and Technology, London.

*Bennett, Christopher John, B.Sc., Research Physicist, Marconi's Wireless Telegraph Co. Ltd., Chelmsford, Essex.

Blakelock, Harold Dennis, B.Sc., Physicist, The General Electric Co. Ltd., Wembley, Middlesex.

Brodie, Ivor, M.Sc., Scientific Staff, The General Electric Co. Ltd., Wembley, Middlesex.

*Carpenter, Eric William, B.Sc., Ph.D., Scientific Officer, U.K. Atomic Energy Authority, A.W.R.E., Foulness, Essex.

Cole, Derek George, B.Sc., Research Engineer, Electric and Musical Industries Ltd., Hayes, Middlesex.

Copsey, William Edward, B.Sc., Physicist, Marconi's Wireless Telegraph Co. Ltd., Chelmsford, Essex.

Davies, Alun Morgan, B.Sc., Lecturer, The Technical College, Reading.

*Duerden, Thomas Ashworth, B.Sc., Ph.D., Senior Engineer, English Electric Co. Ltd., Nr. Preston, Lancs.

Dumbleton, Michael John, B.Sc., Ph.D., Scientist, National Coal Board, Mining Research Establishment, Isleworth, Middlesex.

*Earnshaw, Joseph Brian, B.Sc., Junior Lecturer, University College, Auckland, New Zealand.

Filbey, Gilmour Forbes, B.Sc., Lecturer, Borough Polytechnic, London.

Forester, Ralph, M.Sc., Head of Science Department, Ashton-in-Makerfield Grammar School, Lancashire.

*Goodfellow, Thomas Leslie, B.Sc., Pilot Officer, Royal Air Force.

*Hine, Dennis John, M.Sc., Physicist, Printing, Packaging and Allied Trades Research Association, Surrey.

Holmes, Derek Roy, B.A., D.Phil., Technical Officer, Imperial Chemical Industries Ltd., Plastics Division, Herts.

Inch, William Rodger, B.Sc., Ph.D., Biophysicist, Ontario Cancer Foundation, London Clinic, Ontario.

Jason, Alfred Charles, B.Sc., Ph.D., Principal Scientific Officer, Department of Scientific and Industrial Research, Torry Research Station, Aberdeen.

Jennings, Alfred Peter Henry, B.Sc., A.R.C.S., Senior Physicist, Bailey Meters and Controls Ltd., London.

Minshall, Harold, B.Sc., Assistant Lecturer in Paper Technology, University of Manchester.

Morris, Dewi Pugh, B.Sc., Ph.D., Lecturer, University College of North Wales, Bangor.

Parks, Kathleen Ermine, B.Sc., Physics Mistress, North London Collegiate School, London.

*Preece, William Alfred John, B.Sc., Technologist, Shell Refining and Marketing Co. Ltd., Shell Haven, Essex.

*Redmond, Glyn Beresford, B.Sc., Physicist, Textile Research Division, Dunlop Rubber Co. Ltd., Birmingham.

Rider, John Graham, B.Sc., Ph.D., Lecturer, Battersea Polytechnic, London.

*Ritchie, Ronald Charles, B.Sc., Research Physicist, Dunlop Rubber Co. Ltd., Birmingham.

Robins, Dudley Ambrose, B.Sc., Scientific Staff, The General Electric Co. Ltd., Wembley, Middlesex.

Roy, Satis Chandra, M.Sc., Ph.D., Physicist, Indian Jute Mills Association Research Institute, Calcutta.

Sanson, Arthur, B.Sc., Physicist, Senior Experimental Staff, The General Electric Co. Ltd., Wembley, Middlesex.

Sturley, Cecil Hubert, B.Sc., Physicist, British Nylon Spinners Ltd., Pontypool.

Tittensor, Donald, B.Sc., Technical Staff Officer, Lt. Col., Admiralty Gunnery Establishment, Dorset.

Traub, Wolfie, M.Sc., Ph.D., Senior Research Assistant in Crystallography, Birkbeck College, London.

*Trott Alan John Francis, Research Physicist, A.E.I. Research Laboratory, Aldermaston, Berks.

Wainwright, Harry Vernon, B.Sc., Deputy Section Manager, Polymer Research Section, Dunlop Rubber Co. Ltd., Birmingham.

White, Oliver Morrow, M.Sc., Ph.D., Senior Scientific Officer, Linen Industry Research Association, Co. Antrim.

Wignal, Geoffrey Robert, B.Sc., Physics Master, Kirkham Grammar School, Lancs.

*Wilson, Herbert Rees, B.Sc., Ph.D., Re-Research Scientist, Wheatstone Physics Laboratory, King's College London.

Wood, John Oswald, B.Sc., Manager, Textile Research, Dunlop Rubber Co. Ltd., Birmingham.

Woolfson, Michael Mark, M.A., Ph.D., Lecturer, College of Technology, Manchester.

GRADUATES

Christie, Ronald Henry, B.Sc., Scientific Officer, U.K. Atomic Energy Authority, A.W.R.E., Aldermaston, Berks.

Clother, John Hugo St. Clair, B.Sc., Royal Engineers.

Dove, Geoffrey Thomas, B.Sc., National Service.

Fowler, Peter John, B.Sc., Instructor Lieutenant, Royal Navy.

*Haslam, Roger, B.Sc., Instructor Lieutenant, Royal Navy.

Henry, William James, B.Sc., Scientific Officer, Royal Aircraft Establishment, Farnborough, Hants.

Jessop, Alan Michael, B.Sc., Research Student, University of Nottingham.

Jones, Stanley Peter, B.Sc., Research Physicist, United Glass Bottle Manufacturers Ltd., London.

Leach, Donald Frederick, B.Sc., Research Physicist, British Jute Trade Research Association, Dundee.

Lim, Ho Hup, M.Sc., Document Examiner, Government Department of Chemistry, Malaya.

McLean, Ian Weymouth, B.Sc., Assistant Lecturer in Physics, University of Malaya.

*Mainwaring, Elfed Ernest, B.Sc., Physics Master, Derby School, Derby.

*Mole, John Gordon, B.Sc., Junior Servo-Engineer, De Havilland Propellers Ltd., Herts.

Owen, Geoffrey John, B.Sc., Scientific Officer, British Insulated Callender's Cables Ltd., London.

Roycroft, Donald Martin, B.Sc., Technologist, Shell Refining and Marketing Co. Ltd., Cheshire.

Spoonley, Brian, B.Sc., National Service.

Tinson, Richard, B.Sc., Graduate Apprentice, Metropolitan-Vickers Electrical Co. Ltd., Manchester.

5 Subscribers and 5 Students were also elected.

News of Members

BIRTHDAY HONOURS

The following awards were announced in the Queen's Birthday Honours List :

K.B.E. Sir Thomas Merton (*Fellow*).
C.B.E. F. P. Bowden (*Fellow*).
C. Sykes (*Past President*).
O.B.E. F. J. Harlow (*Fellow*).
A. J. Woodall (*Fellow*).
M.B.E. K. E. B. Jay (*Associate*).
C.M.G. D. H. Black (*Fellow*).

FELLOWS

G. L. Ashdown has been appointed Senior Lecturer at Battersea Polytechnic.

J. W. Boag is now at Mount Vernon Hospital, Northwood, Middlesex.

C. B. Childs has been elected a Fellow of the Royal Society of Edinburgh.

D. Evans was recently promoted to Senior Principal Scientific Officer in the Royal Observatory, South Africa.

B. P. Dudding has been elected an Honorary Fellow of the Society of Glass Technology.

D. Gabor has been elected a Fellow of the Royal Society.

D. W. Gillings is now employed by Imperial Chemical Industries Ltd., Reading, Berks.

T. R. Kaiser has recently taken up a post in the University of Sheffield as Senior Lecturer in Physics.

N. Kurti has been elected a Fellow of the Royal Society.

A. H. Sully has been appointed Director of the British Steel Castings Research Association, Sheffield.

C. Sykes has been awarded the Bessemer Gold Medal of the Iron and Steel Institute.

H. C. Tett is now a Managing Director of the Esso Petroleum Company.

J. Thomson has been appointed Director of the British Scientific Instruments Research Association, Chislehurst, Kent.

ASSOCIATES

R. F. Blackwell is now with Aero Research Ltd., Duxford, Cambs.

G. E. Buckley is Production Controller, Operations Branch, at the U.K. Atomic Energy Authority, Industrial Group Headquarters, Risley, Lancs.

Marion H. H. Bunton has taken up an appointment as Senior Lecturer in Sciences, Homerton College, Cambridge.

J. Critchlow is now Principal of Nelson and Colne College of Further Education, Nelson, Lancs.

M. Davis recently took up an appointment as a Principal Scientific Officer with the U.K. Atomic Energy Authority, Culcheth, Lancs.

T. Emmerson is a Director of Isotope Developments Ltd., Aldermaston, Berks.

H. D. Evans is now at Imperial College of Science and Technology, London, in the Department of Physics.

D. A. Gill is Head of the Technology Division of the Water Research Association, Redhill, Surrey.

F. W. Hayward has now taken up a position as Liaison and Communications Officer with the Reed Paper Group, Larkfield, Kent.

D. John is at the Nottingham and District Technical College, Nottingham.

P. L. Kirby is now employed by Welwyn Electrical Laboratories Ltd., Bedlington, Northumberland, as a Senior Physicist.

E. Linacre has been promoted to Head of the Fire Section of the Safety in Mines Research Establishment, Buxton.

G. M. Michie is now working at C. A. Parsons and Company Ltd., Newcastle-upon-Tyne.

G. L. Miles is now with the Australian Atomic Energy Commission, Sydney.

K. C. Randle has taken up an appointment with Rolls Royce Ltd., Derby.

J. H. Shackley is one of Her Majesty's Inspectors of Schools.

C. B. Sharma has joined the staff of the Government Hamidia Post-graduate College, Bhopal, India, as Professor and Head of the Department of Physics.

G. E. Sharp has taken up an appointment as Lecturer in Physics at the Municipal College, Southend.

P. Tothill is now a Physicist in the Radiotherapy Centre, St. William's Hospital, Rochester, Kent.

H. C. Tresise is now employed by Tube Investments Research Laboratories, Hinxton Hall, Nr. Saffron Walden, Essex.

J. G. Walford is a Physicist with the U.K. Atomic Energy Authority in the Industrial Group of the Research and Development Branch, Thurso, Caithness.

D. Walsh holds an A.E.I. Fellowship and is at the University of Oxford in the Engineering Laboratory.

G. M. Wilcox has recently taken up an appointment with British Nylon Spinners Ltd., Pontypool, Mon., as a Senior Technical Officer.

D. Wilkie is working in the Research and Development Branch of the U.K. Atomic Energy Authority, Sellafield, Cumberland, as a Senior Scientific Officer.

R. W. William is now Assistant Chief Development Engineer in the Guided Weapons Division of the English Electric Company Ltd., Stevenage, Herts.

B. Yates is working in the Research Laboratories of the General Electric Company Ltd., Wembley.

The Institute's Journals

PRINCIPAL CONTENTS OF THE JUNE, 1956, ISSUES

Journal of Scientific Instruments: Volume 33, No. 6

PAPERS

A proportional counter tube for X-ray diffraction analysis. By A. R. B. Skertchly (*University of Leeds*).

An argon-filled, ethyl alcohol quenched counter utilizing a diagonal radiation absorption path is described. The quantum efficiency is 67% when detecting CuKα quanta. When it is used in conjunction with a single-channel pulse amplitude analyser operating with a bandwidth of 3·6 V centred at 30 V its overall efficiency is 46%. Little distortion is introduced into the pulse height distribution curve owing to the incomplete dissipation of the energy of the photoelectrons, and the required low capacitance for high signal-to-noise ratios at low operating potentials is preserved.

Calorimetry by the method of mixtures. By D. W. Plester, S. E. Rogers and Prof. A. R. Ubbelohde (*Imperial College of Science and Technology, London, S.W.7*).

A vacuum calorimeter is described, suitable for measuring heat contents of condensed phases at high temperatures. The heat of fusion of potassium thiocyanate has been evaluated as $H_f = 3{\cdot}39 \pm 0{\cdot}05$ kcal/mol. (mean deviation).

The measurement of frictional forces at vibrating contacts. By J. S. Halliday, A.Inst.P. (*Associated Electrical Industries Ltd., Aldermaston, Berks*).

A simple machine is described which is used for the investigation of wear phenomena at vibrating contacts. It is shown theoretically how the frictional forces at the contacts can be measured and the experimental tests substantiate the theory. Some friction measurements are given which were obtained using brass specimens immersed under silicone oils having a wide range of viscosities. It was found that the friction was least for the medium viscosity oils. The higher friction with the high viscosity oils arose because these oils were pushed aside from the contacts, and with the lowest viscosity oils because they were not as effective in preventing the growth of intermetallic welds as the medium viscosity oils.

A wavelength discrimination spectrometer. By C. R. Forshaw (*Sir John Cass College, London, E.C.3*).

An improved instrument is described, in which arrangements are made for viewing a bipartite field illuminated by lights of desired wavelengths and luminances. The instrument is essentially a prism spectrometer with a double collimator, and produces spectra of high dispersion and intensity. With an artificial pupil of only 1 mm diameter, retinal illuminations of 100 photons (or trolands) can be obtained at wavelengths of 420 mμ and 690 mμ.
Some preliminary results of wavelength discrimination measurements are given to illustrate the performance of the spectrometer.

An X-ray absorptiometer for the determination of tetraethyl lead in petrol. By J. F. Brown and R. J. Weir (*Imperial Chemical Industries Ltd., Billingham, Co. Durham*).

A compact X-ray set suitable for the routine determination of tetraethyl lead in petrol by absorption measurements is described. The X-ray tube, a Ferranti type B100, is operated at 25 kV and 200μA using a projection television high tension generator, and has a short term X-ray intensity stability of ±0·3%. The X-ray detector consists of a phosphor and a photomultiplier. This is capable of determining the concentration of tetraethyl lead in petrol over the range 0 to 1·5 ml./l. (0 to 6 ml./Imperial gallon) with an accuracy of ±0·005 ml./l. (±0·02 ml./Imperial gallon).

A simple monitor circuit for a spectrographic a.c. arc source. By D. F. T. Roberts and E. H. S. van Someren, F.Inst.P. (*Murex Welding Processes Ltd., Waltham Cross, Herts*).

An inexpensive unit is described by means of which the form of the discharge voltage and current and the trigger pulses associated with a spectrographic a.c. arc are displayed, and their phasing determined with reasonable accuracy.

The equipment utilizes a 1 in. type 1CP1 miniature self-focusing cathode-ray oscillograph. A 100 c/s time-base locked to mains frequency is used, with adjustable phase-angle marker "pips" to give a convenient display.

A semi-automatic pen-recorder chart analyser. By C. W. Spencer and G. H. Bazzard (*Radio Research Station, Slough, Bucks*).

A description is given of an instrument which enables a rapid analysis of the variations of displacement of a pen trace upon a moving chart to be made. The pen trace is followed manually by means of a cursor making an electrical connexion with a number of fixed contacts, which are in turn connected through a distribution board to electrically-operated counters. A cam-operated make-and-break switch produces the pulses to actuate any particular counter, determined by the position of the movable contact. The numbers of pulses recorded on the counters are measures of the amounts of time the pen displacement is between pre-selected levels across the chart.

A calorimetric method of determining the energy output of radioactive materials. By A. G. White (*Chemistry Division, Atomic Energy Research Establishment, Harwell, Berks*).

A method of making a direct measurement of the rate of change of temperature with time is described. To do this a large capacity condenser and galvanometer are used in a circuit containing a thermistor as the temperature sensitive element. A description of two calorimeters embodying this principle, with which the energy outputs of radioactive samples may be determined, is given. The theoretical basis of the method is examined and means of estimating correction terms are suggested.

A general purpose electromagnet. By W. Sucksmith, F.Inst.P., F.R.S., and S. P. Anderson (*University of Sheffield*).

A general purpose 10 cm pole diameter laboratory electromagnet is described. Particular attention is given to the magnetic and electrical circuits, and to those features of construction which are thought to be most important.

Fringe spacing in interference microscopes. By F. R. Tolmon and Jill G. Wood (*National Physical Laboratory, Teddington, Middlesex*).

In interferometers employing fringes of constant thickness, where the incidence is normal or very nearly so, the fringe spacing obtained is accepted as equivalent to half the wavelength of the monochromatic light employed. However, in the case of interference microscopes, with high-powered objective lenses producing strongly convergent incident light, experiments show that the equivalent value of the fringe spacing is approximately 10% greater than half the wavelength, a discrepancy undoubtedly due to the obliquity of the rays. The effect is of importance when using interference microscopes for accurately measuring the heights and depths of shallow features on surfaces.

Laboratory and Workshop Notes

A simple visual method of accurately positioning a specimen relative to an X-ray beam.

By P. J. Holmes *and* P. D. Fochs.

An illuminator for detecting air lines in glass tubing.

By S. J. Morrison *and* S. M. Phillipson.

Thin film abrasion tester.

By J. C. Kelly.

A two-circle Geiger counter mounting.

By R. Bones.

A high vacuum magnetic mercury cut-off.

By R. A. W. Haul and E. R. Swart.

A control valve for corrosive liquids.

By J. Hodkinson.

Correspondence

Conduction-cooled vapour traps.

From V. A. Heathcote.

Angle-spring hinges.

From R. V. Jones.

An adaptable mechanism for converting rotary motion into a succession of linear movements.

From P. Grodzinski.

British Journal of Applied Physics: Volume 7, No. 6

SPECIAL ARTICLES

Science and technology in industry. By Sir John Cockcroft, F.Inst.P., F.R.S. (*Published also in this issue of the Bulletin.*)

Stress waves in solids. By R. M. Davies F.Inst.P. (*Department of Physics, University College of Wales, Aberystwyth*).

The aim of this paper is to discuss, in fairly elementary fashion, the topic of the transmission of transient stress pulses of short duration in solids, together with the associated problem of the measurement of pressures subject to very rapid changes. The pressure bar method, devised by Bertram Hopkinson, forms one of the basic experiments in the field and it is described in some detail. An analysis of the limitations of the method leads to a discussion of the change of form of stress wave pulses as they recede from the origin, and the main features of the distortion are discussed when the pulses are propagated in (*a*) elastic solids, (*b*) visco-elastic solids, and (*c*) solids stressed beyond the elastic limit.

PAPERS

The mechanism of pulse temperature rise on the surface of thermionic cathodes. By R. Dehn, A.Inst.P. (*The General Electric Co. Ltd., Wembley, Middlesex*).

During the operation of high- and medium-power pulsed magnetrons, spontaneous fluctuations were observed in the surface temperature of the cathode, during the application of the pulse. On investigation of this effect it appeared that the pulse temperature rise was not due to electron bombardment of the cathode as previously assumed. It seems probable that the effect is caused by resistive heating as current passes through a thin layer of high resistivity at the cathode surface.

The existence of such a layer is confirmed by the findings of other investigators.

Direct carbon replicas from metal surfaces. By E. Smith, and J. Nutting (*Department of Metallurgy, University of Cambridge*).

Two methods have been developed for the removal of carbon replica films directly evaporated on to etched metal surfaces. These involve either electropolishing or chemically etching after deposition of the carbon. The film removed by electropolishing gives a replica of high resolution, whilst with the etching technique extraction replicas may be prepared from multiphase alloys and the extracted phases identified by electron diffraction. Some examples of the application of the techniques to carbon and alloy steels are given.

An extension of the circle and sphere theorems. By G. Power (*University of Nottingham*).

The circle and sphere theorems are here extended to include certain other boundaries along which either the electric potential or the current function takes a constant value. This greatly facilitates the solution of problems preiously treated by *ad hoc* methods, especially in two dimensions where use of the method of conformal transformation can also be made. Illustrative examples are given, showing how these theorems can be applied even when fairly difficult boundary shapes are involved.

Electron optics of X-ray tubes and the design of unbiased sharply-focusing cathodes. By A. R. Lang, A.Inst.P. and D. A. G. Broad (*Cavendish Laboratory, University of Cambridge*).

Using an accurate rubber model, electron trajectories produced by both conventional and various special X-ray tube cathode systems have been studied. Excellent agreement between predicted and observed focal patterns was obtained, in contrast to the results of electrolytic trough measurements reported by Thorp. In conventional cathode systems the effects of space charge were shown to be negligible. A simple unbiased cathode assembly was designed which gave a sharply bounded focal line of width 1 mm.

Apparatus for the measurement of time of impact. By P. L. Kirby, A.Inst.P. (*J. A. Jobling and Co. Ltd., Sunderland*).

Apparatus is described whereby the time of impact of a freely falling sphere on a horizontal surface is measured electrically without direct connexion to the sphere. The time of impact of an 8 mm steel sphere on a solid Pyrex glass slab is 18 μs at room temperature and is the same within ±10% at 700°C. Over this range of temperatures the absorption of fractional impact energy increases considerably and rebound is zero at about 1000°C.

CORESPONDENCE

The suitability of Araldite D resin in photo-elastic investigations.

From C. L. Amba Rao.

A note on the polarization due to oblique reflexion at an aluminized or silvered mirror.

From J. N. Hodgson.